UNIVERSITY OF WASHINGTON

SCHOOL OF OCEANOGRAPHY

4 January 1995

Dr. Joseph H. Kravitz
Code 322GG
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217-5660

RE: Final technical report, N00014-91-J-1678

Dear Dr. Kravitz:

Enclosed are an original and 2 copies of the final technical report prepared by Drs. John Delaney, Russell E. McDuff, and Jean-Christophe Sempere for the above referenced grant entitled, "A Modular Research Approach for Operation in the Northeast Pacific using the JASON/MEDEA-SEA CLIFF-LANEY CHOUEST System to Study Crustal Accretionary Processes."

Sincerely,

Laurie K. Bryan

Laurie K. Bryan
Manager

Encl.

cc: ONR Administrative Grants Officer (1)
Resident Representative N63374

Director, Naval Research Laboratory (1)

Defense Technical Information Center (2)

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DEPARTMENT OF THE NAVY
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IN REPLY REFER TO:

4330
ONR 247
11 Jul 97

From: Director, Office of Naval Research, Seattle Regional Office, 1107 NE 45th St., Suite 350, Seattle, WA 98105

To: Defense Technical Center, Attn: P. Mawby, 8725 John J. Kingman Rd., Suite 0944, Ft. Belvoir, VA 22060-6218

Subj: RETURNED GRANTEE/CONTRACTOR TECHNICAL REPORTS

1. This confirms our conversations of 27 Feb 97 and 11 Jul 97. Enclosed are a number of technical reports which were returned to our agency for lack of clear distribution availability statement. This confirms that all reports are unclassified and are "APPROVED FOR PUBLIC RELEASE" with no restrictions.

2. Please contact me if you require additional information. My e-mail is *silverr@onr.navy.mil* and my phone is (206) 625-3196.

ROBERT J. SILVERMAN

N00014-91-J-1678

FINAL REPORT: CREST '91 Research Program:

SCIENTIFIC USE OF THE JASON/MEDEA SYSTEM ON THE ENDEAVOUR SEGMENT, JUAN DE FUCA RIDGE

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LONG-TERM OBJECTIVES

The primary long-term objective of the program was to provide a solidly founded scientific basis for using the JASON-MEDEA system in its first attempt to conduct a scientific research program.

Additional goals included efforts:

1. to obtain comprehensive, high resolution spatial definition of segment-scale volcano-tectonic-hydrothermal systems along the global mid-ocean ridge system.
2. to utilize nested sets of high-quality base maps to define, constrain and explore theoretical models of submarine magma-hydrothermal systems, and,
3. to document covariation among interlinked physical, chemical and biological processes using instrumental time-series measurements on, above, and below the seafloor.

Support for the program was derived from the US Navy OP-23 group and from the Office of Naval Research.

PROJECT OBJECTIVES

One of the prime reasons for the Crest '91 Project was to initiate the transition of the JASON/MEDEA system from its developmental (sunken ship-finding) phase to its operational phase by demonstrating to potential users, the range and effectiveness of the system in carrying out fine-scale seafloor research. The field portion of Project Crest was designed to explore capabilities of the remotely operated vehicles JASON/MEDEA/AMS 120, configured with a fiber-optic tether, to conduct efficient, multisensor, multiscalar mapping at the regional, local, and fine scales on a 16 km Endeavour Segment of the Northern Juan de Fuca Ridge (Figures 1 and 2).

RESULTS

Acoustic and optical seafloor images spanning a spectrum of scales and resolutions from kilometers to centimeters were the principal products of the Crest '91 program (Figures 3-10). In the final analysis, these images will include the entire central portion of the Endeavour segment (16 km long and 4.5 km wide). This comprehensive data set was obtained during the initial phase of the program using a 120 kHz side-scan-sonar package that yielded spatially coincident bathymetric and backscatter information. To date, a subset of that data has been adequately processed as indicated in the attached figures. Contour interval in this more limited product is 2 meters, and the backscatter information is superimposed directly on the bathymetry to aid geological interpretation. Results have been used during our 1995 summer field program for detailed examination of ridge axis tectonic-volcanic activity and to identify new hydrothermal sites within the axial valley.

In the second phase of the program, JASON/MEDEA operations supported the following sensors: 1) a 200 kHz side-scan sonar system mounted directly on the ROV and operated 20 m

off the bottom; 2) a 675 kHz scanning sonar for high resolution bathymetry, mounted in either a down- or forward-looking mode; 3) a laser profiling system for close range, extremely high resolution mapping of seafloor relief; 4) a wide-angle 1-chip video camera and a close-up 3-chip camera system produced over 150 hours of continuous video coverage; 5) an Electronic Still Camera - produced more than 10,000 images (560 x 480 pixels each) for geological control and visual ground-truth for sonar imaging; 6) a rapid response thermister and a micro conductivity cell completed a water-column survey of unparalleled precision above one of the actively venting hydrothermal sulfide structures imaged in several of the other portions of the program.

Imaging the seafloor in both the acoustic and optical wavelengths was a mixed success. Our initial hope was that we would be simultaneously mapping the seafloor and the water column variability -- an innovation that would have vastly enhanced the efficiency of many ridge crest research programs. Because of the technical difficulties with both navigation and vehicle attitude, we have been unsuccessful at producing actual maps of the seafloor -- meaning that the imagery collected can not be placed in specific spatial contexts based either on the long-baseline navigation or on stability of the JASON vehicle to fix the position of acoustic returns. However, the results have provided some unparalleled geological insights into the seafloor systems and relationships involved in active volcano-hydrothermal systems. The precision water-column mapping effort was a resounding success and the results are being prepared for publication. The optical imaging that did not require attitude control has been extremely useful in refining the seafloor mapping efforts that we are conducting in the Endeavour Segment area.

POST-PROCESSING

Virtually the entire second and third year was devoted to post-cruise processing of selected data sets. Massive effort went into navigational corrections and data processing. The original (at-sea) long-baseline navigation was largely a disaster, we have extracted the best information from the data that is possible, but at present we remain in possession mainly of images, not maps. The processing routines for the AMS-120 data sets were originally extremely cumbersome; a vast amount of energy was expended and a large amount of time to little benefit. Several trips to Woods Hole were made in an effort to refine the approaches, but publishable products eluded us. Recently, using funding from alternate sources (the University of Washington and Woods Hole) we have been able to utilize very recently developed, more user-friendly data processing routines evolved within the Deep Submergence Group to satisfy the requirements of follow-on programs by other investigators. With these routines we have finally processed much of the original data for the first time during the summer of 1995. We now have 3 graduate students and a post-doctoral researcher working on this data set to produce highest quality results for publication (Delaney et al., 1996, Robigou et al., 1996). In addition, we are currently developing digital terrain models of subsets of our survey area (Blondell et al., 1996).

An extensive effort has also focused on the attitude data stream for the JASON vehicle. The compass/gyro system on the vehicle was apparently completely inoperative during major portions of the field program -- a condition that did not come to light until mid-cruise; at that time, the problem could not be solved and usable results were not recoverable throughout the remainder of the program. As a consequence, most of the 200 kHz imagery and all of the 675 kHz data are virtually unusable with meaningful resolution because of the erratic track-line of the JASON vehicle. This problem has apparently been corrected and the JASON system is now operational in the manner originally expected for the Crest '91 program. The optical data sets, both video and Electronic Still Camera, are of usable quality and are being utilized to expand and refine geological and biological mapping in the areas that coverage exists (Robigou et al., 1993; Juniper et al., 1994). Electronic Still Camera images have been placed in mosaics which delineate major geologic features with a resolution and coverage not previously available. These results are now being released in the form of papers built on our recent success in interpreting the

AMS side scan sonar data. The laser system did not work more than one meter from the outcrop being mapped and it was deemed too dangerous to use in such close quarters on a routine basis.

MULTISCALAR IMAGERY OF SEAFLOOR VOLCANIC SYSTEMS

The series of images in Figures 3-10 illustrate one of the major successes of the Crest '91 program. Beginning with Figures 3 and 4. the setting for the most well-processed AMS-120 line is shown in comparison to the resolution possible from SeaBeam data of the Endeavour Axial Valley. Close inspection of Figures 4B and D indicate clearly that the morphology of the seafloor can be generally recognized, but the difference in resolution between the two data sets is nearly two orders of magnitude - the multibeam data is gridded at 100 m and the bathymetry from the side scan data is gridded at about 1.2 meters. Figure 4C is the backscatter amplitude data digitally draped on the bathymetric data generated from the same survey. Figure 5 is an enlargement of Figure 4D showing the level of detail that is available. The arcuate faults along the head wall of the slump blocks migrating into the axial valley imply a new approach to considering axial valley tectonics.

Figures 6 and 7 are views from the north of the same data set providing a distinctly different perspective and allowing the details of the side-scan backscatter imagery to be compared closely with the bathymetry. The power of these images is that they can be used almost directly to interpret the geological relationships in the axial valley. The fact that we have had more that 100 ALVIN dives in the same area allows us to interpret these images with considerable certainty regarding the actual relationships depicted and the captions of the individual figures convey some of this information.

Figures 8 and 9 are a series of progressively closer views of the backscatter imagery with annotations and commentary in the captions. The terrain imaged is very reminiscent of calderas in basaltic volcanoes - the primary difference being that the elongate character of the axial valley is the dominant feature at a spreading center. The nature of the benching process is one of the most intriguing elements of neotectonics to evolve from these types of data sets and we are developing a model of the mechanisms by which the slump-block bench-like features develop. This type of complete imaging at this resolution of major ridge crest features has not yet been published and we are close to finishing a manuscript for JGR based in part on the results shown in this report.

Figure 10 presents two different types of mosaics using the digital imagery from the Electronic Still Camera. The image in 10A is from a down-looking configuration on the JASON vehicle, and shows a typical ropy lava flow that is truncated and offset downward on the right side of the image. This down-dropped block is the western edge of the fissure shown in Figure 9A at about the point that the upper arrow extending from the label "fissure" touches the fissure itself. Figure 10B was constructed from ESC imagery collected with the camera oriented in a horizontal mode. The sulfide structure shown is the same one shown in figure 9B and was the site of the extensive water-column survey referred to below.

The series of images just described accomplishes one of the primary objectives of the Crest '91 program which was to provide a complete set of nested data sets in which seafloor structures could be examined at all scales ranging from the basin scale, to the scale of an individual structure with resolvable tube worms.

PRECISION PLUME SURVEY

A widely applied approach to estimating the thermal output of the oceanic crust involves measurement of thermal anomalies within the Neutrally buoyant, laterally spreading effluent layer produced by hydrothermal plumes. However, the quantitative relationship of these anomalies to

the flux of heat is obscured by a lack of detailed knowledge of the characteristics of waters being entrained into the rising plume and the rate of entrainment. To address this problem, we used the ROV JASON to conduct detailed surveys within rising plumes.

Two kinds of data were obtained during the hydrothermal plume component of the program: 1) passive mode data collected during all operations with long baseline (meter resolution) navigation and 2) active mode data collected in precisely controlled survey patterns (to about 10 centimeters) with EXACT navigation using 300 kHz SHARPS transponders (centimeter resolution). For the active mode work, JASON was operated in closed-loop control, providing the ability to repeatedly and precisely follow tracklines through the core of an intense black smoker plume during several tidal cycles. An example of the survey data is shown in Figure 11 which depicts the temperature fields at on three horizontal surfaces (at 2175, 2160 and 2150 meters depth) above the S&M structure.

Data analysis focused on three aspects of the active mode observations: 1) computing estimates on a series of horizontal surfaces, the integral of McDougall's (EPSL, 99, 185 (1990)) "q" value. The quantity "q" should be conserved within a hydrothermal plume, therefore it is a critical cross-check on the quality of the observations, 2) determining the characteristics of the fluid component that is entrained (which is mostly ambient sea water that has been "contaminated" by earlier discharge and/or diffuse venting), and, 3) establishing the role of variable vent salinity on plume development. An important element of this analysis has involved addressing limitations of the practical salinity scale (PSS-78) and the sea water equation of state (EOS-80) which strictly apply to a particular composition of the sea salt component. We found that high levels of silica in vent fluids produce a significant deviation away from these standards and required development of a set of new procedures to reduce the raw sensor data. The overall data set strongly suggests that "q" is not conserved, especially at higher levels within the plume. Our interpretation of this discrepancy is that it results from the coalescing of plumes emanating from multiple sources on a vent structure, so that simple plume theory does not apply.

A review paper on the dynamics of hydrothermal plumes was published by McDuff (1995) and two manuscripts are in preparation, one discussing the interpretation of data from conventional CTD instrumentation in hydrothermal environments and the other on the structure of the plume emanating from the S&M vent in the main Endeavour field.

COMPUTER IMAGE ANALYSIS OF GEOLOGICAL RELATIONSHIPS

A major effort has been devoted to produce a textural analysis of the 120 kHz side scan sonar imagery. This new generation of high-resolution sonar systems produces large amounts of data. Routine interpretion of such surveys in terms of geologically meaningful information requires sub-sampling the data so that it can be conveniently manipulated. Specific image processing algorithms were developed, for structure-tracking and textural analysis. Linear features are detected through a gradient-based method, called adaptive filtering. Structure-tracking provides lengths, directions, histograms of local directions, and sinuosities for all detectable structures and will be used in detailed tectonic analysis.

Textural methods are concerned with the local variations of luminosity in the images, and discriminate tectonic settings according to their relative textures. These textures are quantified with statistical parameters deduced from Grey-Level Co-occurrence Matrices (GLCM). For each point in the numerical image, the GLCM $P_d(i,j)$ computes, for a finite window, the number of times a pixel of grey-level i will be at distance d from a pixel with grey-level j. Examples of the parameters available include **homogeneity**, associated with the smoothness of the local texture, and **entropy**, a measure of roughness. Figure 12 indicates how the relationships between

homogeneity and entropy can be used to distinguish different types of terrain's based on selections in well known areas based on our previous work in the area.

Characteristic geologic settings Robigou and Delaney. Identification with known rock types and structures is derived from ground-truth information, provided by analysis of video records, electronic still cameras images, and direct observations from submersibles. Subsets of these terrain's are used for computation of reference parameters. Through clustering, and semi-supervised classification algorithms, all points in the numerical images are assigned to specific classes, identifying different geological and tectonic settings.

Algorithms developed for textural analysis and structure-tracking are rapid, versatile, and easy to use for non-specialists. They provide maps of quantifiable parameters. Through this quantitative recognition, we are now working toward the definition of textural parameters, which would be independent of sensor geometry, or of sensor wavelength. Broad and intensive comparisons of data sets, in different regions, and at different scales, will allow the definition of a database of textural (geological) parameters, associated with specific terrain's. Preliminary work by Blondell et al., 1993 has established that there are distinct differences and the current manuscript (Blondell et al., 1996) has used that earlier approach to map an entire section of sonar data according the characteristics defined above.

VIRTUAL REALITY JOURNEY TO SUBMARINE VOLCANO

During the 1991 cruise, the idea of a low-level 'bombing run' was conceived and implemented in which the AMS system was used in an unconventional mode to "fly" within 50 meters of the bottom along the length of the Axial Valley. Normal separation was at least 100 meters; the result was that some absolutely unparalleled imagery of the details of the axial valley were obtained and these have been used in an unusual manner. We have worked closely with scientists from the Human Interface Technology Laboratory here at the University of Washington and with researchers from a newly developed Seattle firm, Ambiente, Inc. to produce a complete immersion experience in the data set. The most accessible product of this effort is a 30 minute video that has be prepared and is available to scientists and educators who write for it. It clearly indicates the ONR credits for the initial effort. The program begins with an overview of the NE Pacific and progressively moves through cascading, nested data sets on the Endeavour that were detailed during the Crest '91 program; it transits more than 5 decades of scales from 1000's of km to cm's in resolution. A copy of this video was provided to Dr. J. Kravitz during the 1994 AGU Fall Meeting in San Francisco.

An aggressive program is also being conducted this year with the NASA Digital Image Analysis Laboratory at JPL to produce a full resolution fly-through video of the entire data set. This product will be made widely available at cost to educators and researchers alike.

COMPLEMENTARY NATURE OF ALVIN AND JASON

Based on our dual use in terms of field work, ALVIN and JASON are strongly complementary systems for working the seafloor. ALVIN is used to best advantage in well-mapped areas; it has highly effective and adaptable sampling, manipulative, and payload capabilities. JASON/MEDEA can be a remarkably effective, efficient, and adaptable seafloor and water-column mapping tool. At present the manipulative and sampling capabilities of ALVIN vastly outweigh such capabilities on JASON. Several major elements that would contribute to effective multiple use of the two systems in tandem would include compatible navigation systems, and means of displaying the imagery collected using JASON while in the submarine, and an especially effective means of processing the data collected using JASON for use in ALVIN programs.

DELAYS IN PUBLICATION

Owing in part to the difficulties encountered in processing the navigation and the side scan data set itself for Crest '91 AMS work, we have used our 1995 NSF-funded ALVIN dive program to field check key parts of the imagery. We find that as suspected the data are not of the quality one would hope for in terms of producing truly navigated "maps" of the seafloor. However, with the corrections available from our most recent program, we are confident that the sonar imagery is indeed adequate for depicting the relative geology of the seafloor and we are proceeding to release the results of some of the better imaging efforts in publication form. Based on what we have seen from subsequent programs using the DSL systems, the results of Crest '91 are sufficiently high quality and are sufficiently well field-checked that the ensemble of acoustic-optical images represented herein is certainly as good subsequently obtained data sets. At least in part our reluctance to publish had to do with not knowing how good or how bad the data actually were. Following the recent field season, we can publish with definable levels of error in our "mapping data".

ASSESSMENT

Prior to our program in Crest '91, the DSL assets had been used exclusively to find objects on the seafloor. Ours was the first scientific use of the systems and there were distinct cultural-practical differences that existed between the two groups and the two approaches. Had the program been successful in all regards as initially conceived, it would have represented a major step forward in our ability to conduct medium and fine-scale mapping of seafloor systems. As it turned out, at a minimum, the program provided a much needed shake-down opportunity for the DSL systems in the world of science. We understand that subsequent programs have successfully imaged the seafloor in a variety of ways, and navigation and vehicle attitude were not a major problem (D. Yoerger, pers. comm.)

Data processing proved to be a very difficult hurdle to overcome during the post-cruise portion of this program. As indicated in the foregoing discussions and the attached images, we have persevered with the help of our colleagues at WHOI who have substantially redone the software necessary to reduce the data, and the results are distinctly gratifying. Using additional funding from other sources we continue to pursue further refinement of the approaches and the interpretation stages of the overall data base. Despite the fact that the difficulties encountered in collecting and processing this <u>first-ever data set</u> have been monumental, we feel that the program in general has been successful. Further, as the processing and interpretation skills have grown we have developed major new insights into the relationships between deformation and hydrothermalism on the seafloor by studying the 120 kHz imagery which provides resolution and coverage heretofore lacking in ridge crest studies.

The Endeavour has be selected by the RIDGE program as one of the sites for its Ridge Crest Observatory program. Although difficult to cope with, this complex and extensive Crest '91 data set will be utilized for years to come by a wide variety of researchers at the University of Washington and at other universities to study the Endeavour Segment as an analogue for many of the basic interactions that occur along ridge crests.

PUBLICATIONS

Blondel, P., V. Robigou, J.C. Sempéré and J.R. Delaney, (in prep.), Quantitative seafloor characterization at mid-oceanic ridges: applications to Endeavour Segment, Juan de Fuca Ridge.

Blondel, P., V. Robigou and J. C. Sempéré, 1993, Textural analysis and geological mapping of high-resolution sonar images: applications to Endeavour Segment, Juan de Fuca Ridge, EOS, Trans. AGU, 74, 573.

Blondel, P., J. C. Sempéré and V. Robigou, 1993, Textural analysis and structure-tracking for geological mapping: Applications to sonar images from Endeavour Segment, Juan de Fuca Ridge, Proc. IEEE Oceans 93 Conf., III, 208-213.

Blondel, P., J. C. Sempéré, V. Robigou and J. R. Delaney, 1993, High-resolution bathymetry and geology of Endeavour Segment, Juan de Fuca Ridge, EOS, Trans. AGU, 74, 573.

Delaney, J. R. and Crest-Flange 1991 Research Teams, 1991, JASON/ALVIN operations on the Endeavour Segment, Juan de Fuca Ridge-Summer 1991, EOS, Trans. AGU, 72, 231.

Delaney, J.R. and others (1995) Observatory Studies in the Northeast Pacific: EOS, Trans. AGU, 76, 706.

Delaney, J.R. and others (1996) Multiscalar studies of vigorous hydrothermal systems in the NE Pacific. JGR submittal - February, 1996

McDuff, R. E., 1991, Observations within a rising hydrothermal plume made from the Jason ROV, EOS, Trans. AGU, 72, 232.

R.E. McDuff (1995) Physical dynamics of deep-sea hydrothermal plumes, in S.E. Humphris, R.A. Zierenberg, L.S. Mullineaux and R.E. Thomson (eds.), Physical, chemical, biological and geological interactions in hydrothermal systems, AGU Monograph 91, pp. 357-368

Robigou, V. and J. R. Delaney, 1994, Evolution of two hydrothermal vent fields on the Endeavour Segment, Juan de Fuca Ridge, EOS, Trans. AGU, 75, 706.

Robigou, V., J. R. Delaney and D. Stakes, 1993, The High-Rise hydrothermal vent field, Endeavour Segment, Juan de Fuca Ridge, Geoph. Res. Lett., 20, 1887-1890.

Robigou, V., J. R. Delaney and W. Colony, 1991, Comparison of hydrothermal vent fields, Endeavour Segment, Juan de Fuca Ridge, EOS, Trans. AGU, 72, 232.

Sempéré, J.-C., J. R. Delaney, R. E. McDuff, K. Stewart, D. Blackman, V. Robigou and C. Wilkerson, 1991, Preliminary results from a multi-sensor survey in the Endeavour Segment, Juan de Fuca Ridge, EOS, Trans. AGU, 72, 455.

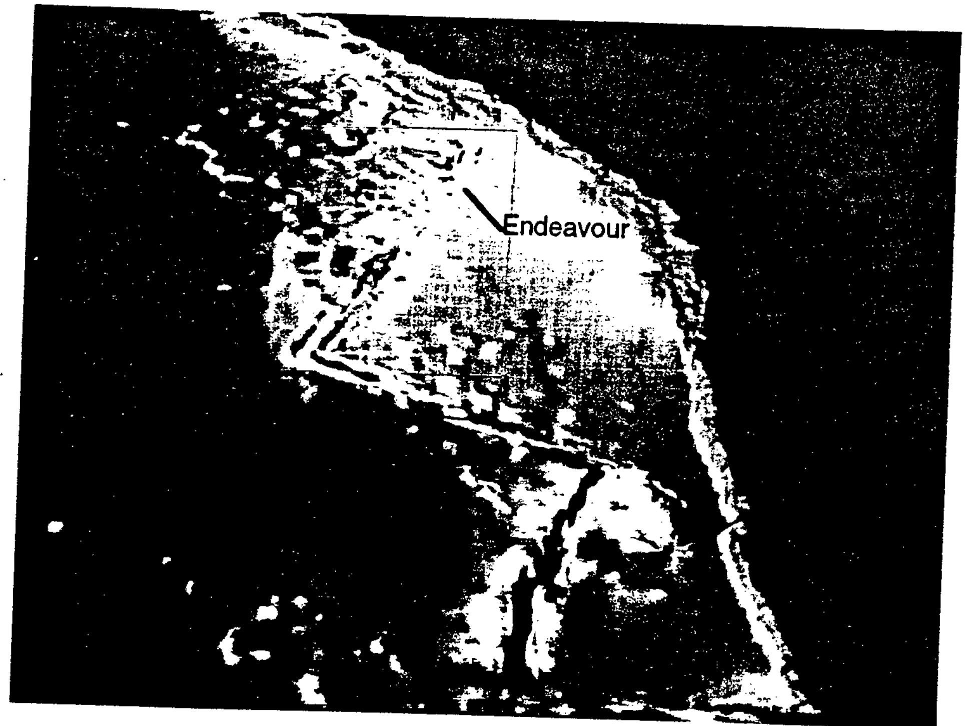

Figure 1. Regional view of N E Pacific showing Mendocino Escarpment, Gorda Ridge, Blanco Fracture Zone, Juan de Fuca Ridge. Bathymetric data gridded at 1000 m.

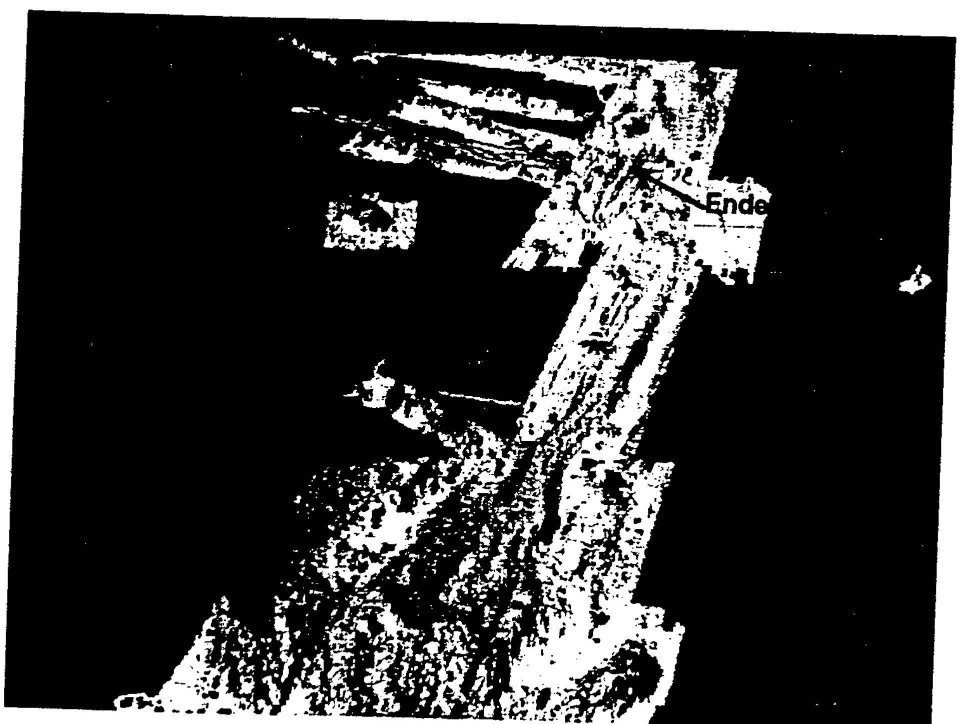

Figure 2. Multibeam bathymetry, gridded at 400 m, showing the northern Juan de Fuca Ridge from Axial Seamount to the Souvanco Fracture Zone. The Endeavour Segment is flanked east and west by parallel ridges. See Figure 3 for detail.

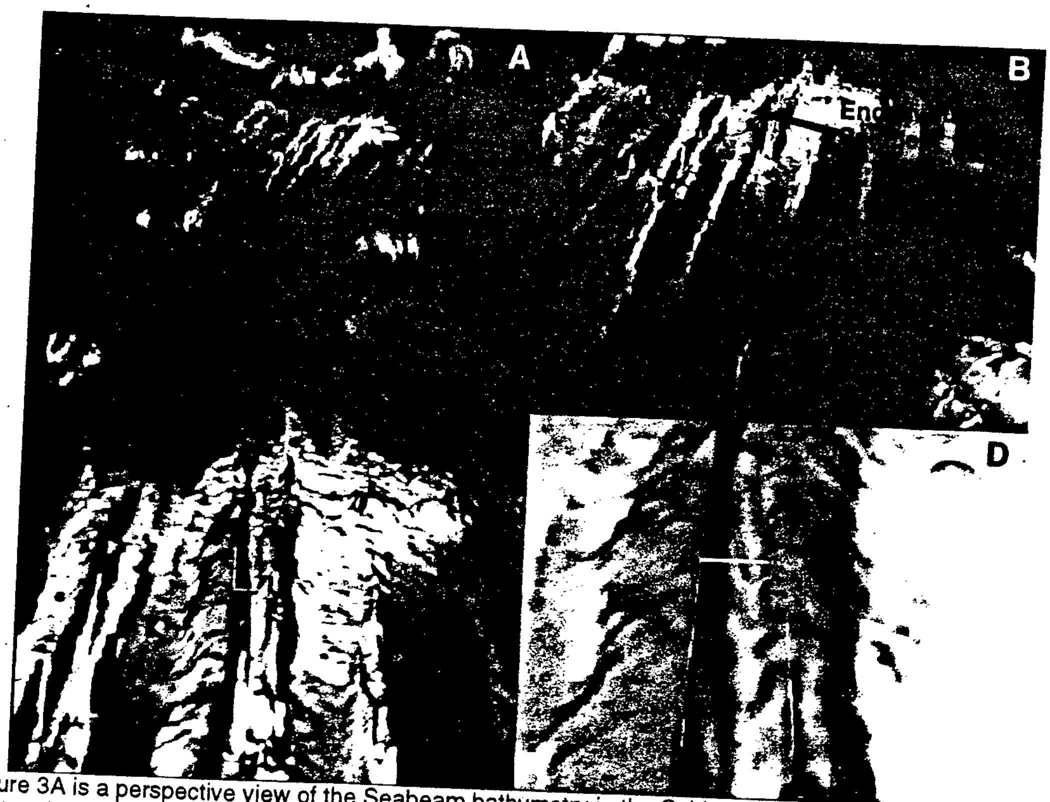

Figure 3A is a perspective view of the Seabeam bathymetry in the Cobb overlapping spreading center showing Split Seamount and the Endeavour Ridge; 3B and 3C are enlargements of portions of 3A; Figure 3D is close-up view of axial valley of the Endeavour Segment Ridge.

Figure 4A is the same as Figure 3D for comparison with Figure 4B in which the color palette is changed to make warm colors deep and cool colors shallow. Figures 4C and D are processed backscatter and bathymetry from the AMS-120 side-scan sonar imaging of the Endeavour Axial Valley. The swath is 1 km wide and 2.3 km long

FIGURE 5. Perspective view of the Endeavour axial valley bathymetery from the south. Resolution is 1.2 meters per pixel. The bathymetric data are derived from a survey using the AMS-120 kHz side scan sonar system with a phased transducer array towed about 50 meters above the center of the axial valley floor. Geologic features: asymmetry of the axial valley, location of a massive accumulation of sulfides just to the south of the Main Endeavour Vent Field (MEF), venting fluids up to 380-400°C along the western wall of the valley, and the deep lava-filled basin to the east of the MEF. Northward, there are several large blocks of basaltic material that rise above the valley center. One horst, at the north end is the locus of the High Rise Vent Field (HRF) containing at least one actively venting sulfide structure that rises nearly 50 meters above the surrounding valley floor (Robigou et al., 1993).

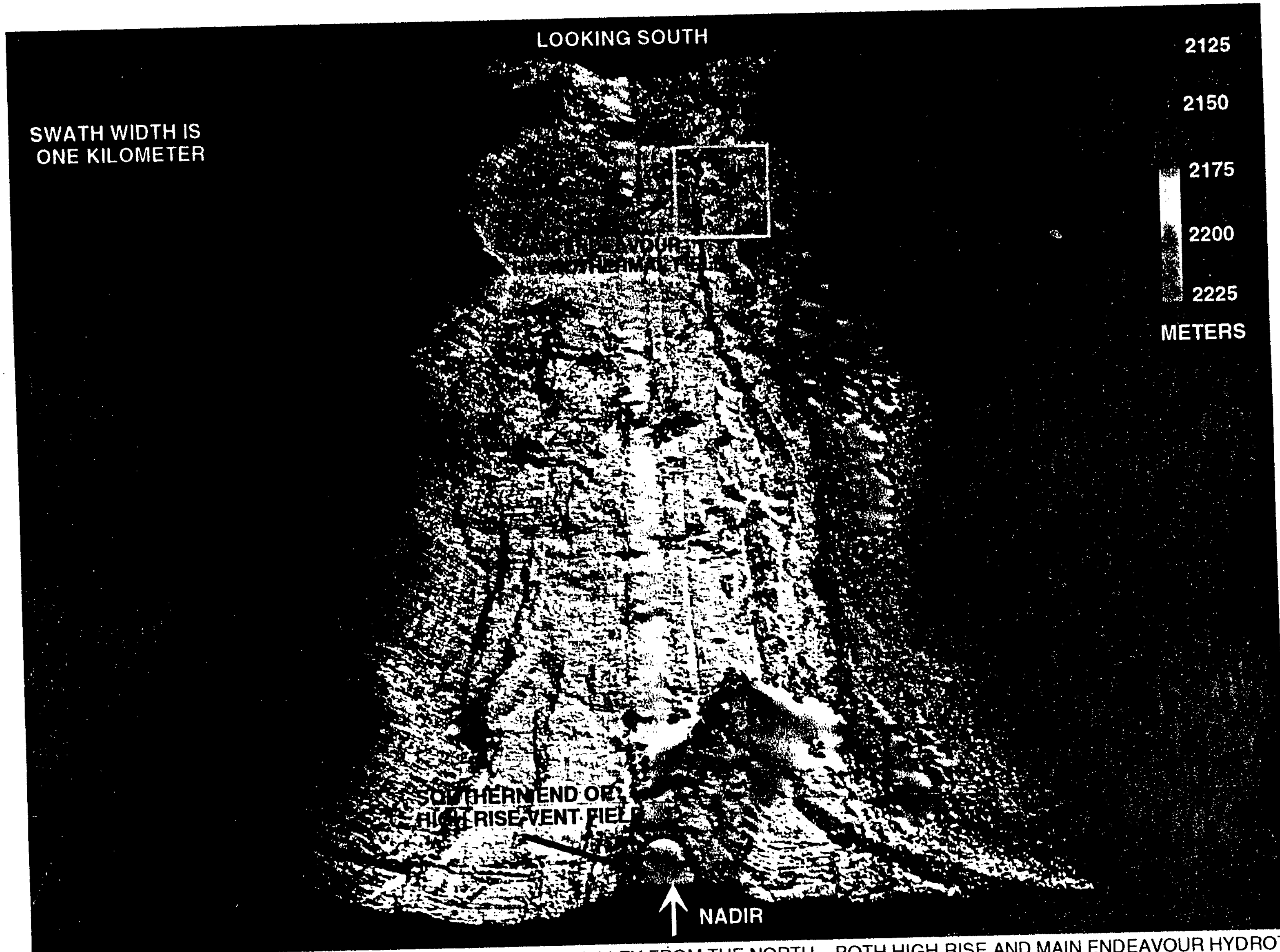

FIGURE 6. BATHYMETRIC IMAGE OF THE ENDEAVOUR AXIAL VALLEY FROM THE NORTH. BOTH HIGH RISE AND MAIN ENDEAVOUR HYDROTHERMAL SYSTEMS ARE VIGOROUSLY VENTING HIGH TEMPERATURE FLUIDS THROUGH LARGE, STEEP-SIDED SULFIDE STRUCTURES. THE EVOLUTION OF THE ENDEAVOUR AXIAL VALLEY APPEARS TO HAVE INVOLVED EXTENSION AND SUBSIDENCE TO FORM THE AXIAL VALLEY BY ALTERNATE EPISODES OF SLUMPING OR CALVING OF THE NORMAL FAULT-BOUNDED WALLS, INTERSPERSED WITH VOLCANIC ERUPTIONS. AT PRESENT, EXTENSION IS THE DOMINANT PROCESS AND HYDROTHERMAL ACTIVITY IS ESPECIALLY VIGOROUS. COMPARISON WITH FIGURE 7 DEMONSTRATES THAT THE VERY SMOOTH AREAS ARE ZONES OF SHADOW WHERE THE CONTOURING PROGRAM HAS STRETCHED THE SURFACE.

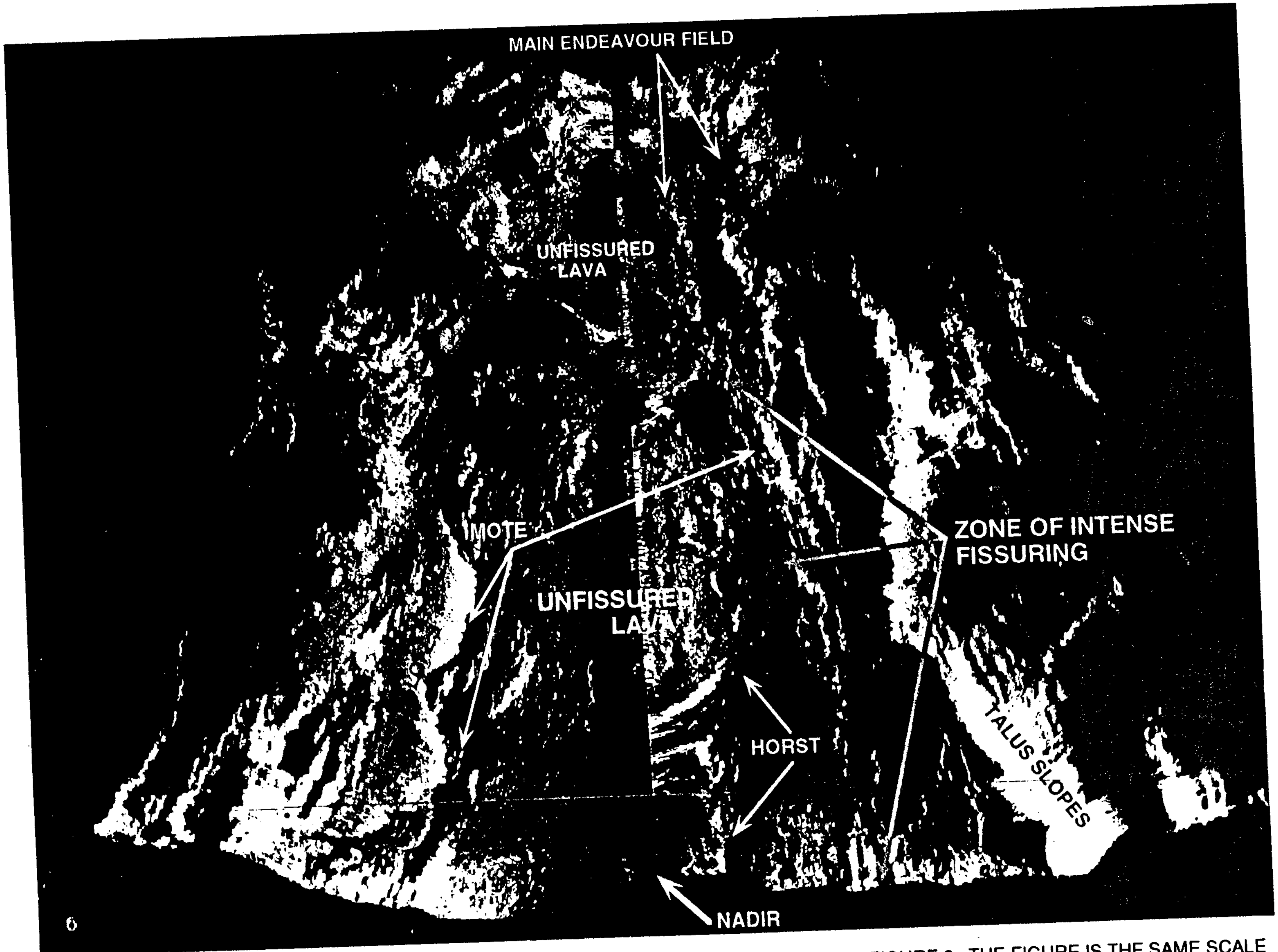

FIGURE 7. BACKSCATTER AMPLITUDE DATA DIGITALLY DRAPED ON THE BATHYMETRY FROM FIGURE 6. THE FIGURE IS THE SAME SCALE AND ORIENTATION AS AS FIGURE 6; THE CENTERLINE TRACE IS THE NADIR. THE 120 KHZ PACKAGE WAS TOWED AT AN ALTITUDE OF 50 METERS ABOVE THE AXIAL VALLEY. LIGHTEST GRAYS ARE TALUS SLOPES. ON THE EAST WALL THREE OF THESE SLOPES HAVE BENCH-LIKE OUTCROPS AT ABOUT THE SAME ELEVATION ON THE SLOPES.

FIGURE 8A. ENLARGEMENT OF A SECTION OF FIGURE 7 SHOWING DETAIL OF FISSURE ZONE ALONG BASE OF WESTERN WALL AND COLLAPSED LAVA LAKES IN FOREGROUND. NOTE BENCH IN DISTANCE - POINT X IS SAME IN BOTH FIGURES

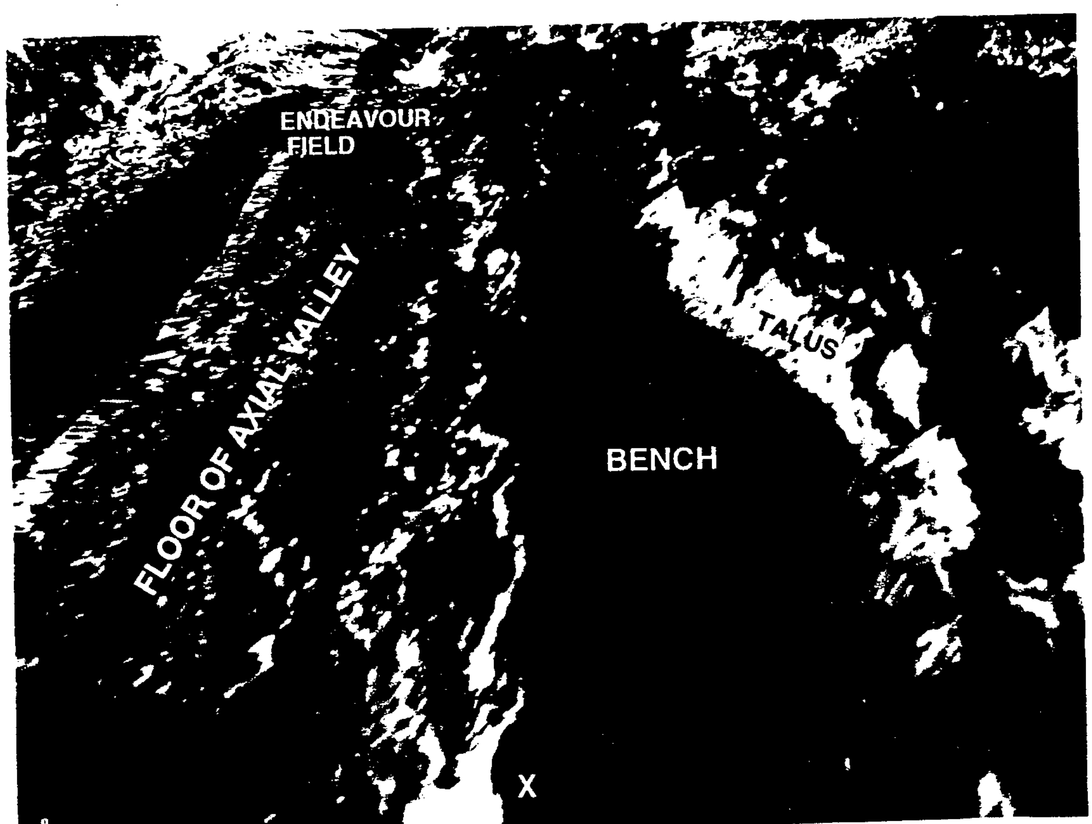

FIGURE 8B. SHOWING DETAIL OF BENCH FROM FIGURE 8A AND THE DEVELOPMENT OF A YOUNG FISSURE AT THE EDGE OF THE BENCH.. IN THE DISTANCE IS THE ENDEAVOUR HYDROTHERMAL VENT FIELD

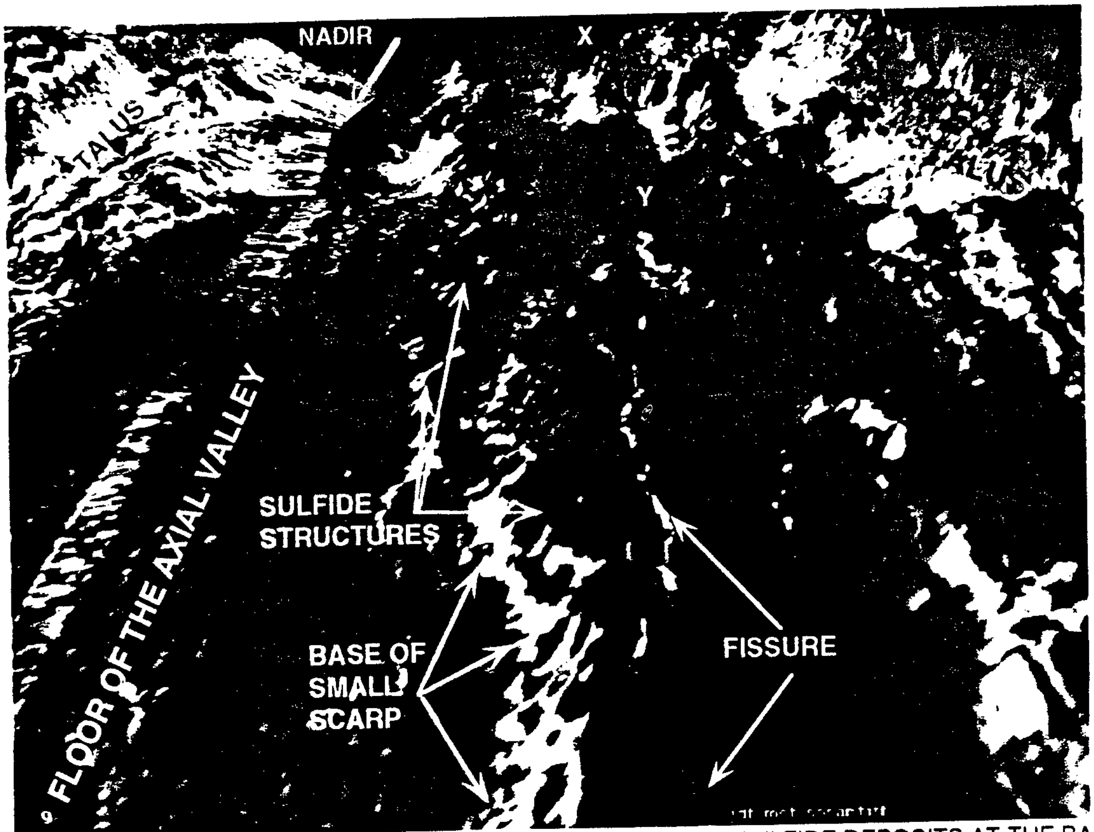

FIGURE 9A. THE ENDEAVOUR VENT FIELD SHOWING EXTINCT SULFIDE DEPOSITS AT THE BASE OF THE SCARP AND THE RECENT FISSURE AT THE TOP OF THE SCARP THAT LOCALIZES VENTING. THE LETTERS "X" AND "Y" IN THIS FIGURE ARE INDEXED TO THOSE IN FIGURE 9B.

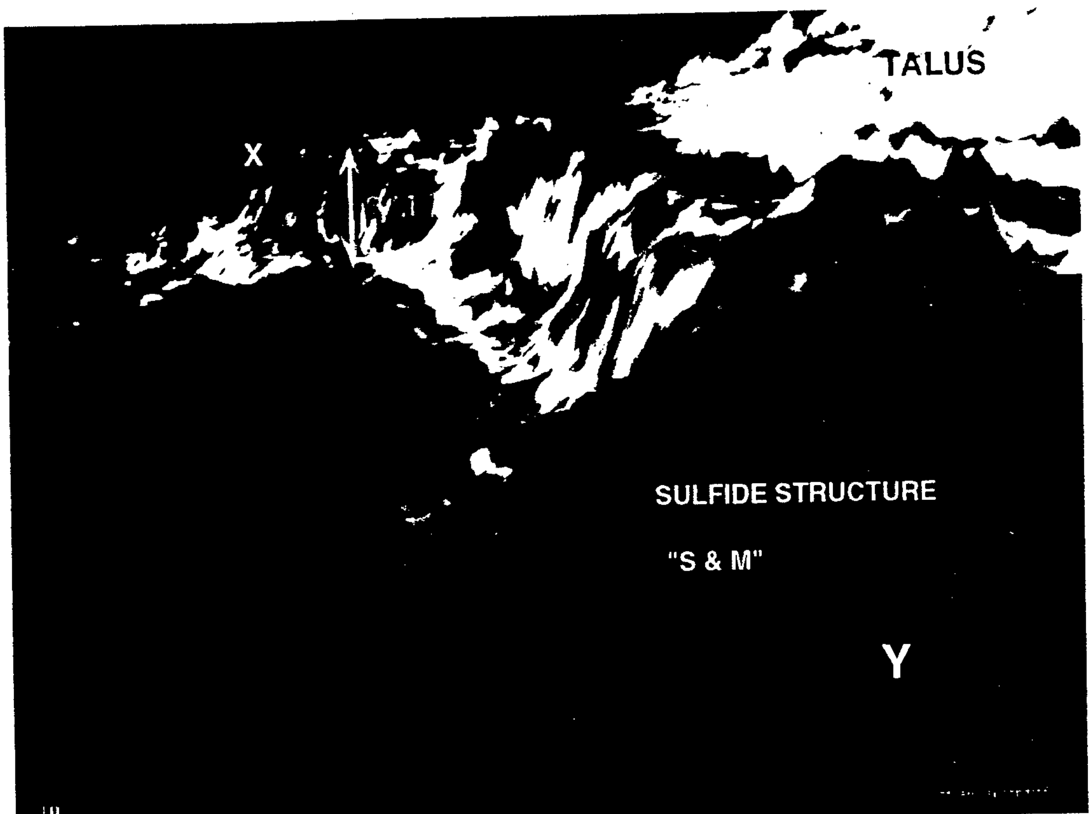

FIGURE 9B. DETAIL OF THE SOUTHERN PORTION OF THE MAIN ENDEAVOUR VENT FIELD SHOWING VERTICAL OFFSET ALONG AN EIGHT METER HIGH SCARP. THE FISSURE HAS EVIDENTLY LOCALIZED VENTING WHICH HAS FORMED THE MASSIVE SULFIDE STRUCTURE IN THE FOREGROUND KNOWN AS "S & M" (FOR SMOKE AND MIRRORS). IT IS VENTING FLUIDS THAT ARE 366° C WITH A SALINITY ONLY 35% THAT OF SEAWATER.

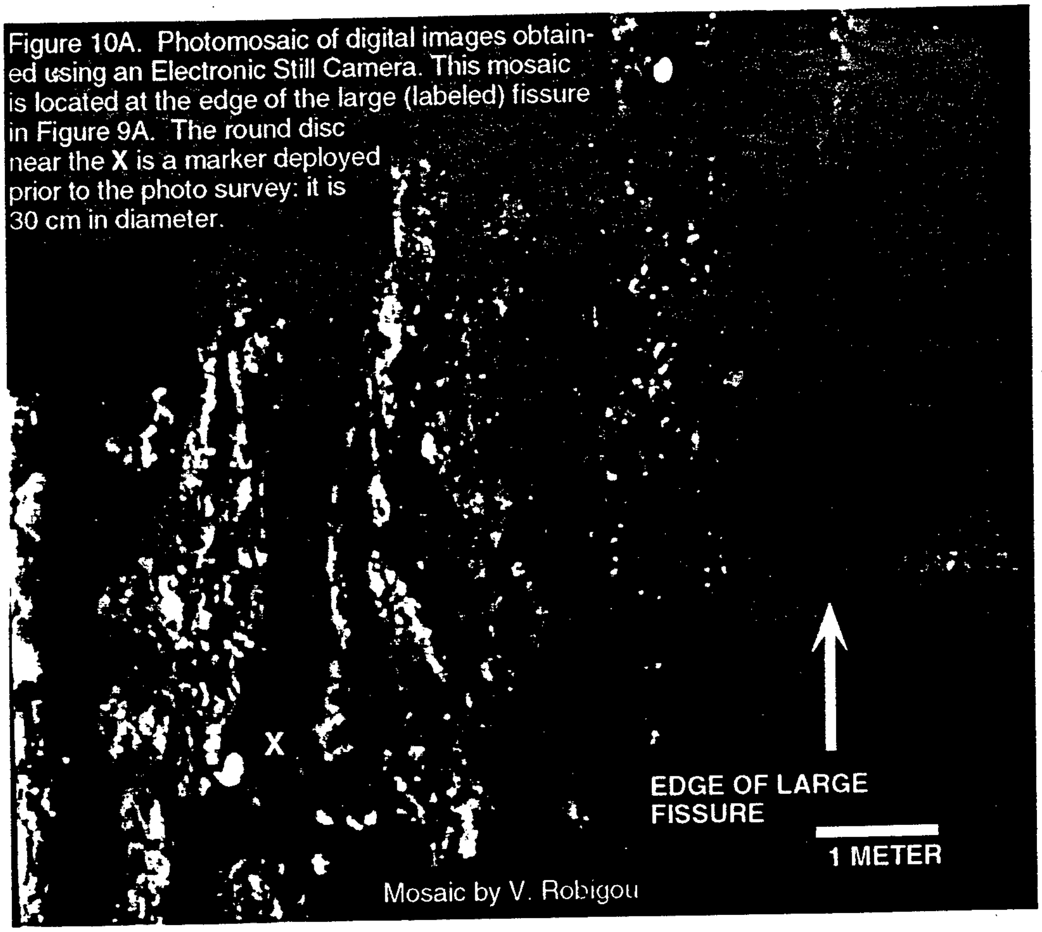

Figure 10A. Photomosaic of digital images obtained using an Electronic Still Camera. This mosaic is located at the edge of the large (labeled) fissure in Figure 9A. The round disc near the **X** is a marker deployed prior to the photo survey: it is 30 cm in diameter.

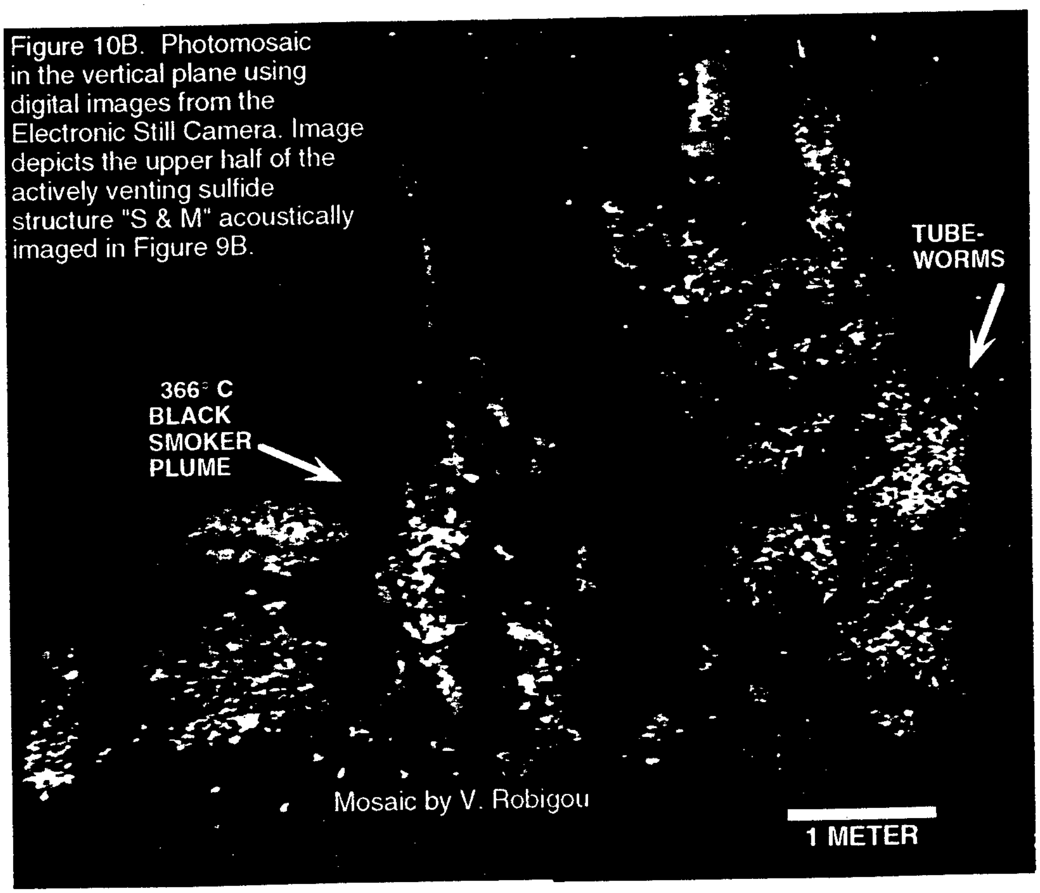

Figure 10B. Photomosaic in the vertical plane using digital images from the Electronic Still Camera. Image depicts the upper half of the actively venting sulfide structure "S & M" acoustically imaged in Figure 9B.

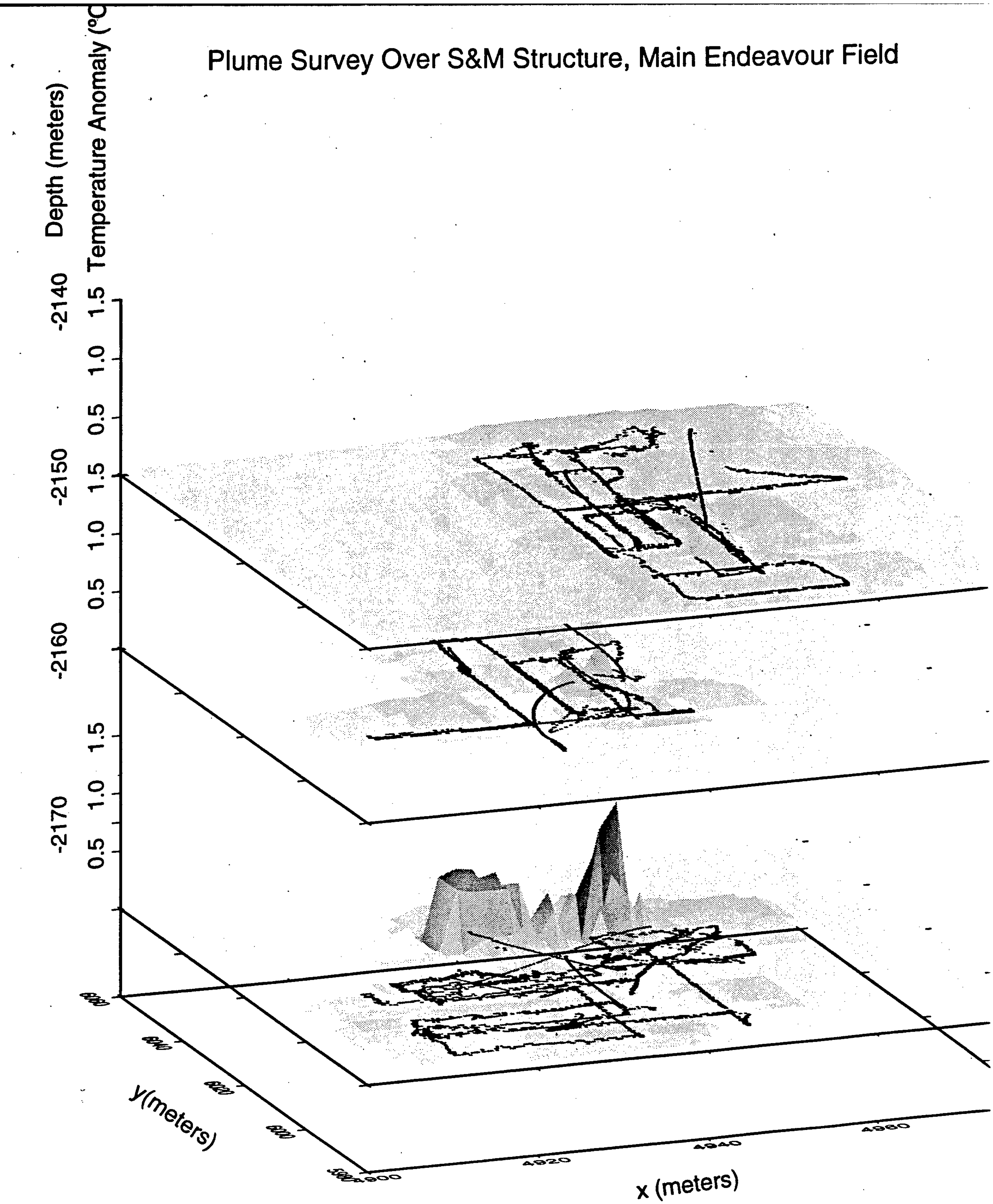
Plume Survey Over S&M Structure, Main Endeavour Field
Depth (meters)
Temperature Anomaly (°C
-2140
-2150
-2160
-2170
1.5
1.0
0.5
1.5
1.0
0.5
1.5
1.0
0.5
y(meters)
x (meters)
4920
4940
4960

Figure 11

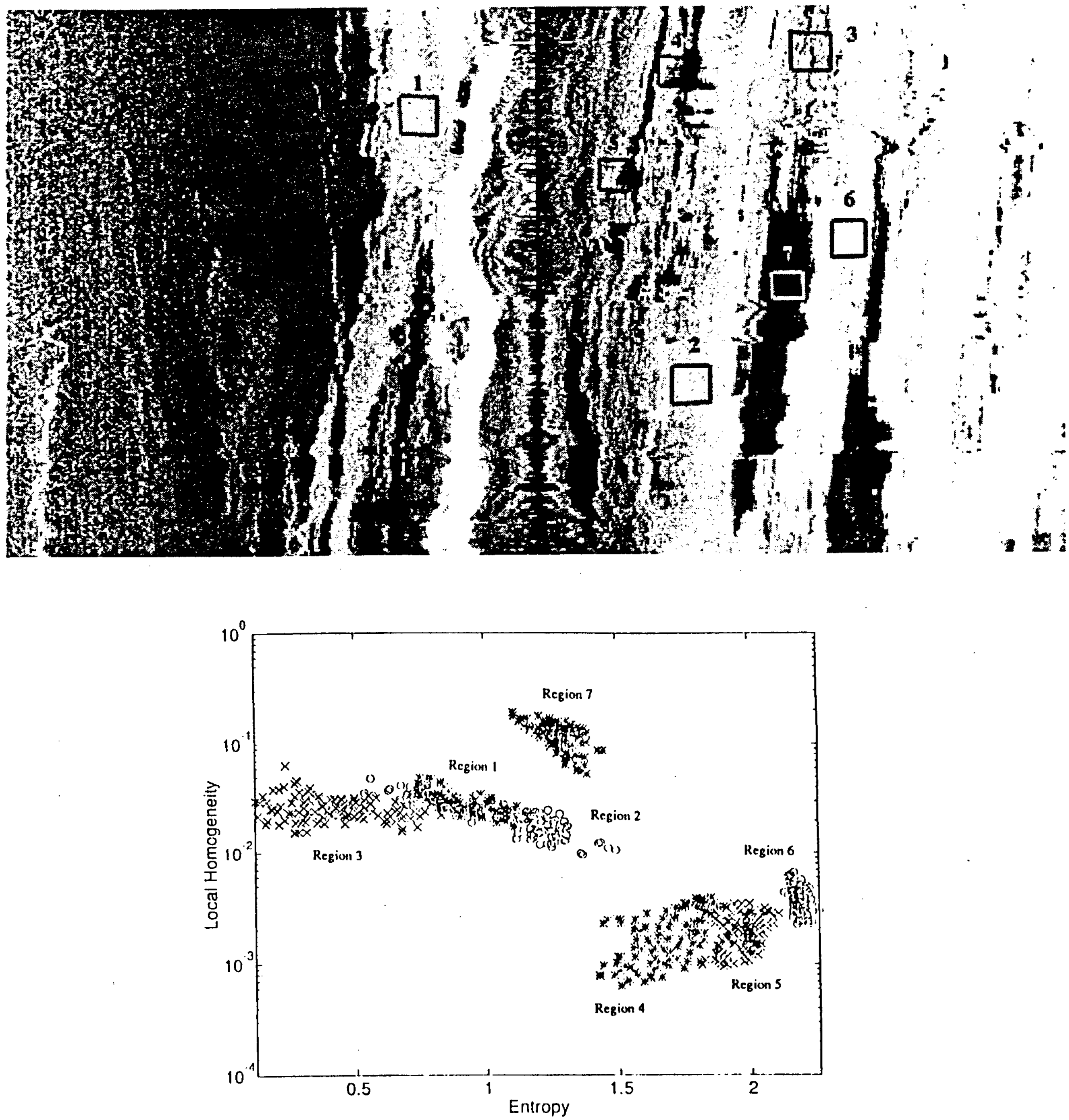

Figure 12: Diagram showing entropy vs. local homegeneity for the first 7 training zones.

Region 1:	talus, pillow basalts	stars
Region 2:	lava flows	circles
Region 3:	faults	crosses
Region 4:	hydrothermal vent	stars
Region 5:	hydrothermal vent	crosses
Region 6:	lava type	circles
Region 7:	shadows	stars